United States
Department of
Agriculture

Forest Service

Forest Health
Protection

Forest Health
Technology
Enterprise Team-
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FSCBG Implementation Into SpraySafe Manager -- A Decision Support System

FHTET 96-02
February 1996

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...als, and plants. Follow the directions and heed all ... Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

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FSCBG Implementation Into SpraySafe Manager -- A Decision Support System

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Executive Overview

This report summarizes the initial development of a highly user-friendly, personal-computer-based program called SpraySafe Manager, using as its computational engine the USDA Forest Service aerial application prediction model FSCBG (Forest Service Cramer-Barry-Grim). SpraySafe Manager is a cooperative effort of the USDA Forest Service, Forest Health Protection staff, and New Zealand Forest Research Institute. In its initial configuration SpraySafe Manager is the first step toward the development of a useful decision support system for pest control agents (eventually incorporating additional data and other models besides FSCBG). The preliminary version detailed herein predicts the deposition of material within the swath of an aircraft, and drift downwind, toward and into potentially sensitive (non-target) areas. Current options in SpraySafe Manager enable the user to visualize the ground deposition, estimate the effectiveness of the spray operation, and examine the sensitivity of results to changes in aircraft and environmental conditions.

Summary

One of the natural extensions of the USDA Forest Service aerial application prediction model FSCBG (Forest Service Cramer-Barry-Grim) is the prediction of dose (pest control agent) and its biological response (on target and non-target species). Combining the ability of the model to predict spray deposition and atmospheric dispersion accurately with biological effects models, and interpreting these results in light of application productivity and cost benefits, are the ultimate goals of this model extension. To reach these goals, the USDA Forest Service and New Zealand Forest Research Institute joined during November 1995 to initiate development of a stand-alone, highly user-friendly decision support system (called SpraySafe Manager) that would take advantage of the accurate predictions from FSCBG, but with a simple, easy-to-use and easy-to-understand user interface. This report reviews the initial steps taken toward our goals to date, subsequent code implementation, and the possibilities and anticipated features to be added to the program as SpraySafe Manager is developed further. Ultimately, once we can predict dose and couple in its biological response, we will have a way to estimate what it takes to control a target or non-target organism, set buffer zones and other spray mission restrictions, and estimate what the overall costs will be to do so.

The author wishes to acknowledge the support of the USDA Forest Service (through John Barry) and New Zealand Forest Research Institute (through John Tustin), the advice and program direction given by Brian Richardson, and the programming skills of Phillip Middlemiss.

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Glossary

A short list of the important words and expressions used in this report include:

Bout Width	The lane separation between adjacent aircraft flight lines.
Cost-Benefit	An accounting of the costs involved in spraying a herbicide or pesticide, balanced by the benefits envisioned by this operation (retention of plants or trees, beautification, site clearing, etc.).
Dose-Response	The response of an organism to increasing dose applications of a herbicide or pesticide. Dose-response is generally fit to a simple curve for model predictions.
FSCBG	The USDA Forest Service Cramer-Barry-Grim aerial application prediction model, operational on personal computers, with over 170 user group members nationally and worldwide. This model provides the computational power for the decision support system.
NOEL	The No-Observable-Effects-Level, a dose level for which the response of an organism is assumed either negligible or effectively nil.
SpraySafe Manager	A program developed by the USDA Forest Service and New Zealand Forest Research Institute as a first step toward a highly user-friendly, personal-computer-based decision support system for herbicides (in New Zealand) and pesticides (in the United States). SpraySafe Manager is envisioned as a stand-alone program in New Zealand, and as an option within FSCBG in the United States.

1. Introduction

Over the last twenty-five years the USDA Forest Service has been pursuing the development of computer models to predict the dispersion and deposition of aerially released material. The two current models available are AGDISP (Bilanin et al. 1989) and FSCBG (Teske et al. 1993). FSCBG (for Forest Service Cramer-Barry-Grim) predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP (for AGricultural DISPersal) near-wake model, contained within FSCBG, solves a Lagrangian system of equations for the position and position variance of spray material released from each nozzle on the aircraft. The FSCBG far-wake model begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian dispersion equation to recover ground deposition. The combination of AGDISP within FSCBG presents a powerful predictive tool for dispersal of spray material from multiple line sources, including evaporation, canopy penetration, and accountancy and environmental fate.

FSCBG has undergone continued development, refinement and enhancement over its lifetime (Dumbauld, Bjorklund and Saterlie 1980; Bjorklund, Bowman and Dodd 1988; Curbishley and Skyler 1989; Teske and Curbishley 1991, 1994). Model validation is an ongoing priority with the model (validation summaries may be found in Teske, Barry and Thistle 1994 and Teske, Thistle and Barry 1996). A real-time version of FSCBG for GPS/GIS applications has been developed (Teske, Barry and Thistle 1995). The near-wake portion of the model has been selected by the Spray Drift Task Force (SDTF), and renamed by them as AgDRIFT, as the model of choice for pesticide registration (Teske et al. 1996). The Canadian Spray Drift Task Force has decided on the near-wake model as well (accessing it through the FSCBG interface) as its model of choice for buffer zone prediction (R. E. Mickle, 1995, private communication). Plans are underway to include FSCBG in three developing decision support systems: GypsES, the gypsy moth decision support system under development by the USDA Forest Service, Morgantown, WV, to monitor the spread of the Gypsy moth and track the spray projects contracted to contain its movement; SpraySafe Manager, an aerial application decision support system under development by the USDA Forest Service, Davis, CA, and New Zealand Forest Research Institute (FRI) for herbicide use; and ASPEX, a mosquito control decision support system under development by the USDA and the U. S. Air Force Reserve.

This paper summarizes the development to date of SpraySafe Manager, and the role played by FSCBG. An overview of the decision support approach taken in SpraySafe Manager may be found in Mason et al. (1991), with a summary of the philosophy behind SpraySafe Manager in Richardson (1995) and general decision support strategy involving FSCBG in Teske, Barry and Thistle (1996).

2. Philosophy and Approach

FSCBG is a powerful computer model for predicting the deposition and atmospheric dispersion of sprays released by aircraft, with its near-wake model providing a computationally efficient way of determining the ground deposition pattern beneath a spray aircraft. In an effort to simplify the input requirements to FSCBG for herbicide applications, Richardson (1995) suggested the development of a separate, highly user-friendly personal computer program (called SpraySafe Manager) which would access FSCBG as its computational engine. Initial program development combining SpraySafe Manager with FSCBG would act as a starting point for a later, more comprehensive decision support system. Richardson's proposed approach to decision support is remarkably similar to suggestions made in a much earlier document (Weeks, Blacksten and Coffey 1982), even to the inclusion of FSCBG.

Here we describe the initial programming of FSCBG/NZ (NZ for New Zealand) into SpraySafe Manager, as a first step toward the development of a comprehensive herbicide application decision support system. While SpraySafe Manager invokes FSCBG as a subprogram (in the New Zealand application), it is anticipated that the SpraySafe Manager interface will also exist as a subprogram within FSCBG itself (in the United States). Also, herbicide use is just the first step in the development trail of the anticipated decision support system, later to include such important features as cost-benefit analysis, model sensitivity, user training, and decision options.

In the initial (and subsequent) development of SpraySafe Manager, it was important to build the personal computer interface for operation within Microsoft Windows, with a programming language that offers flexibility in screen presentation, extendibility as the model becomes more complicated, and extensive database support. For these reasons -- plus access to a programmer with skills to carry out the work -- the interface development system Delphi (from Borland) was chosen (written in the Pascal programming language). This interface would access FSCBG/NZ subroutines (written in the Microsoft Fortran programming language) in a separate dynamically linked library (or DLL), and together create a complete program. By keeping the scientific subroutines in Fortran, their portability to other platforms (such as the other decision support systems currently under development, and AgDRIFT) would be ensured. With two programming languages involved, some time was necessary to communicate between the two (passing inputs and recovering results), but all of that was straightforward, since nothing was being done that had not been done before.

It was felt that the entry of only a minimum number of easily-understood and familiar inputs would be essential to the appeal of SpraySafe Manager. The inputs decided upon are:

Aircraft Type
Boom Height (in m above the ground)
Spraying Speed (kph)
Application Rate (L/ha of the tank mix)
Temperature (deg C)
Relative Humidity (percent)
Wind Speed (kph)
Wind Direction (deg from flight direction)
Spray Block Width (m)
Distance to Sensitive Area (m)

Sensitive Area Width (m)
Bout Width (or Lane Separation) (m)
Nozzle Type and Spray Material
Number of Nozzles

Libraries contain the aircraft information (with details of wing semispan or rotor radius, weight, and engine characteristics) and nozzle information (nozzle type, orientation, and spray material); the user has only to select from a table of possibilities. Figure 1 presents the simple geometry chosen for the spray block, downwind distance and sensitive (or non-target) area in the first configuration of SpraySafe Manager. All other input parameters are clearly familiar to anyone working in aerial application.

Calculations initially generate the solution to one flight line (one-half bout width upwind of the downwind boundary of the spray block). Sufficient downwind data points are included in the calculation to interpolate for the deposition within the spray block and downwind to and across the sensitive (non-target) area for the farthest upwind flight line anticipated. The computed downwind deposition (plotted on the screen for the user to see) is then used in the following program modules in SpraySafe Manager:

Environmental

The single flight line result is overlapped for the number of flight lines needed to cover the spray block, and then plotted on the screen. The buffer distance for the specified non-target plant species is then determined. Total spray accountancy (an accounting of where all of the released material goes) is calculated, and represented by the percentages of released active spray material deposited in the spray block, deposited in the distance to the sensitive (non-target) area, deposited in the sensitive (non-target) area, and remaining aloft beyond the sensitive (non-target) area. These percentages are shown on the screen, and also plotted in a pie chart rendition.

Efficacy

The overlapped flight lines in the spray block may be used to compute the mean deposition found there, and its standard deviation (leading to the CV = standard deviation divided by the mean deposition). The dose-response relationship for the spray material and target plant species is then quizzed to recover a table presenting the spray level, percentage of area covered within the spray block, and percentage of plant control.

Productivity

These results enable the user to determine the productivity of the spray project (cost in $/ha and work rate in ha/hr), once additional distance, time and monetary information is supplied.

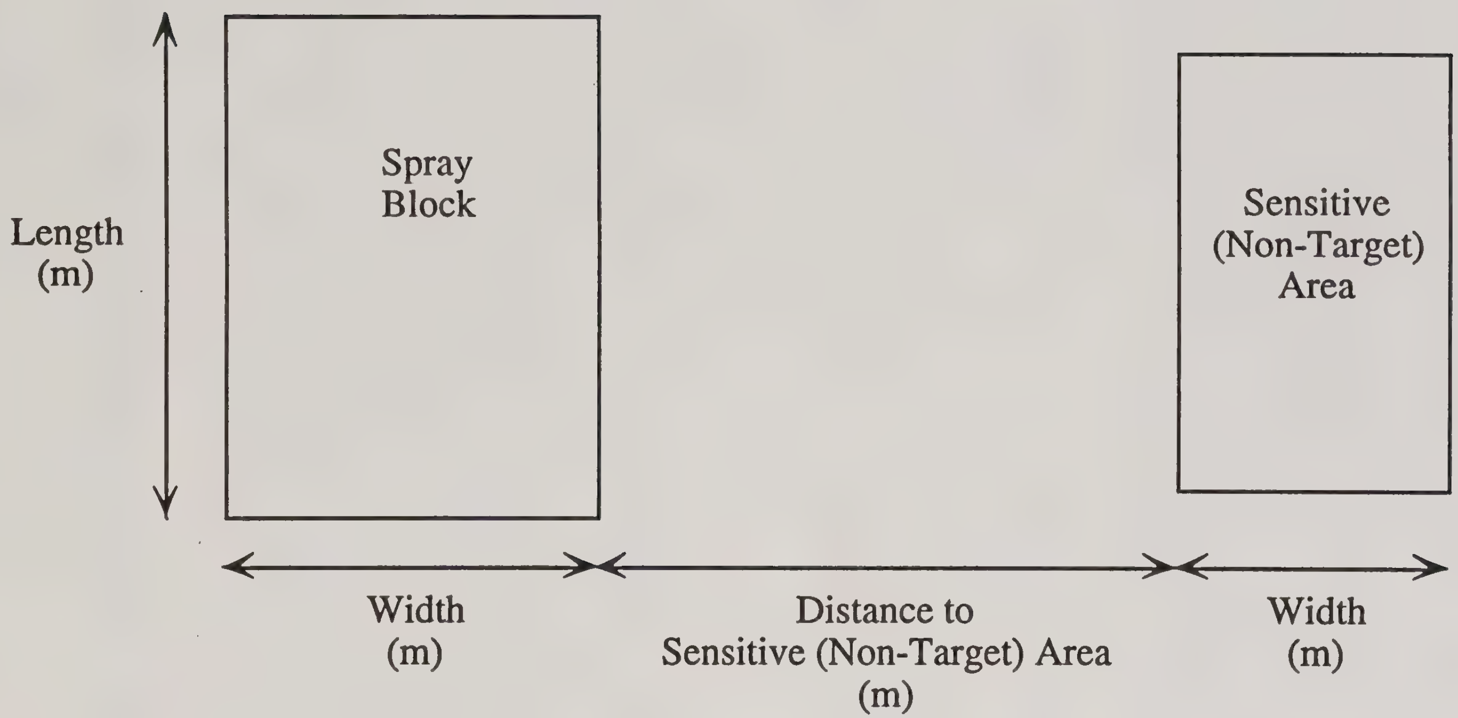

Figure 1. Simplified spray block geometry for SpraySafe Manager. The aircraft flies the length of the spray block from the bottom of the figure to the top. The horizontal length at the left is the Spray Block Width (in m), the length in the middle is the Distance to the Sensitive (Non-Target) Area (m), and the length on the right is the Sensitive (Non-Target) Area Width (m).

3. Technical Considerations

The equations for the near wake model in FSCBG have been presented elsewhere (Teske et al. 1993) and will not be repeated here. Instead, we now detail the formulation followed to extend the predicted deposition results into dose response.

Previous work by Richardson, Ray and Vanner (1993) demonstrates that the distribution of spray block deposits may be closely approximated by a normal distribution following a logarithmic transformation of the deposition. The important parameters are the mean of the deposition in the spray block (where spray lines are separated by bout width) and coefficient of variation (CV), which represents the standard deviation of the normal distribution (both mean deposition and CV are computed by FSCBG). The deposition area may be found from the cumulative distribution function ϕ by the equations

$$\phi(x) = \begin{cases} \dfrac{1 + \operatorname{erf}(x/\sqrt{2})}{2} & x \geq 0 \\ \dfrac{1 - \operatorname{erf}(-x/\sqrt{2})}{2} & x \leq 0 \end{cases} \tag{1}$$

where erf is the error function (approximated by a formulation given in Abramowitz and Stegun 1964) and

$$x = [\ln d - \text{mean}] / \text{sdev} \tag{2}$$

where d is the deposition level of interest, mean is the logarithm (ln) of the average deposition (determined by the overlap procedure in FSCBG/NZ) and sdev is the standard deviation of the overlapped deposition in logarithm space. For example, Figure 2 was generated by the default inputs to SpraySafe Manager, where mean = 4.560 and sdev = 0.122. In this case the desired deposition level of active was 10.414 L/ha (100 percent of active applied) while the average deposition level of active within the spray block was computed to be 9.953 L/ha (95.6 percent of active applied). The percentage of area covered by the desired deposition (and higher) level of active may be computed by first finding $x = 0.370$ from eqn 2, and then $\phi = 0.644$ from eqn 1, for an area coverage of 35.6 percent for all deposit of active above 10.414 L/ha. Figure 2 illustrates that at 100 percent of desired active applied, the cumulative fraction is 0.644, implying that a fraction of 0.356 of the spray block receives at least 100 percent of the desired deposition level. Differences in two deposition levels may be found by computing ϕ twice (once for each level) and then subtracting.

Dose response is generated by fitting field or laboratory data to a symmetrical sigmoid curve (following Richardson, Miller and Ray 1994) of the form

$$U = \frac{D - C}{1 + \exp[-2(a + b \ln d)]} + C \tag{3}$$

where the four parameters a, b, C and D describe the dose response behavior of a plant species to a specified herbicide. A typical curve (for $a = 2.2$, $b = -1.9$, $C = 0$ and $D = 1$) is

shown in Figure 3, where for example a deposition level of 4 L/ha of active applied permits a fraction of 0.3 of the weeds (competing vegetation) to survive (thereby controlling 70 percent of the weeds). Clearly, given a value for the deposit level of active (in L/ha), the use of eqn 3 will recover the response to that dose in terms of the fraction of weed control predicted.

It is then possible to take the summary results of FSCBG/NZ (the mean and standard deviation of the deposition in a spray block), combine them with a specified dose-response biological curve, and construct tables from which spray effectiveness may be evaluated (and plotted as shown in Figure 4). In this figure area covered (from eqn 1 and 2) and weed control (from eqn 3) are shown cumulative to 100 percent of active applied. The overall weed control percentage (a weighted average with area covered, in this case 75.6 percent) characterizes the effectiveness of the scenario calculated by FSCBG/NZ and the specified dose-response information, and provides a single quantitative answer for a specific spray scenario.

Productivity is computed using the Banaugh (1984) formulation of the Baltin-Amsden approach (Amsden 1960) as implemented by Richardson and Goldingham (1987) and Curbishley, Teske and Barry (1993).

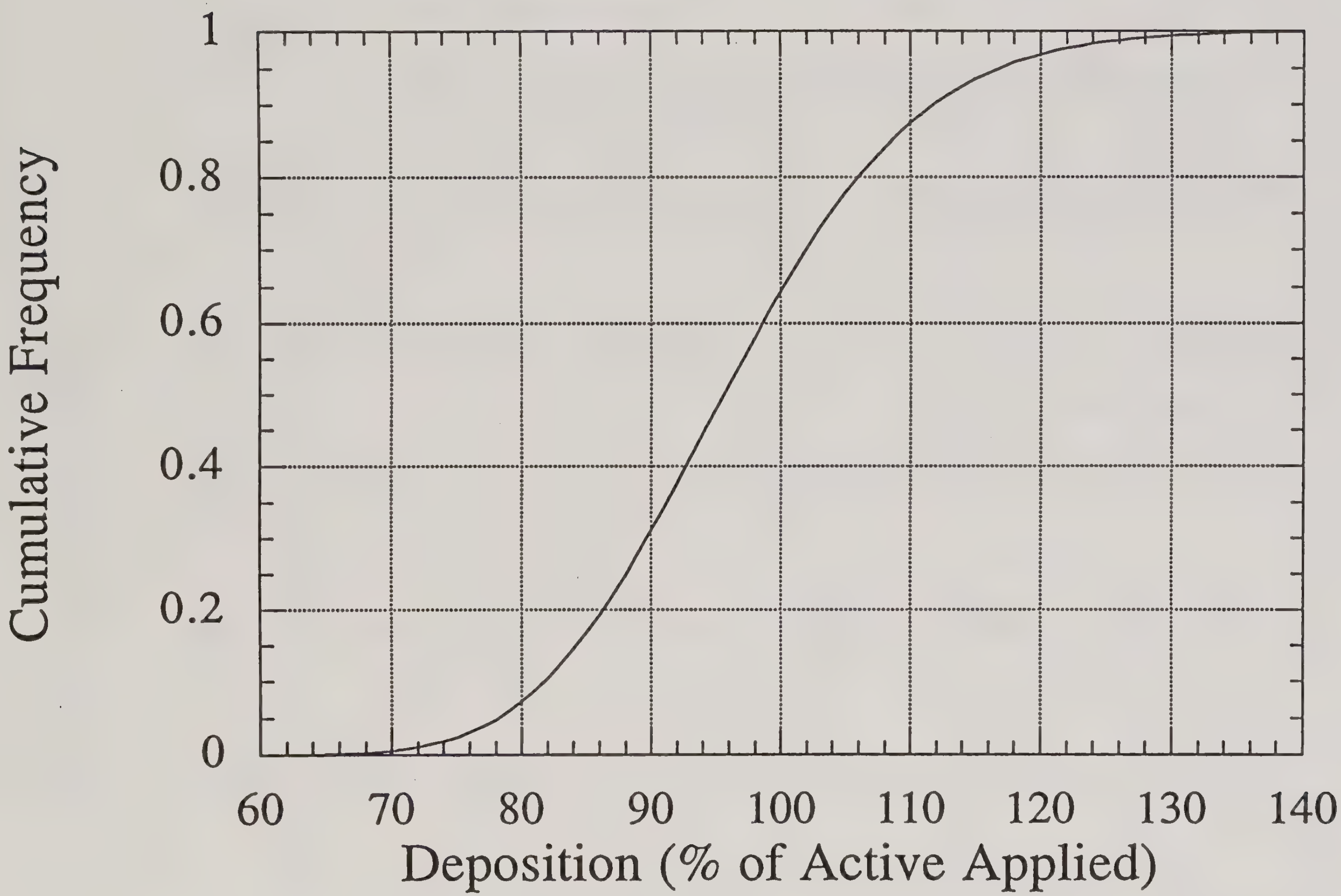

Figure 2. A typical frequency distribution of field deposit (following Richardson, Ray and Vanner 1993). The parameters generating this case (with eqns 1 and 2) are logarithmic mean = 4.560 (which corresponds to a mean deposit of 95.6 percent of active applied) and logarithmic standard deviation = 0.122; the vertical scale gives the cumulative area covered (to unity).

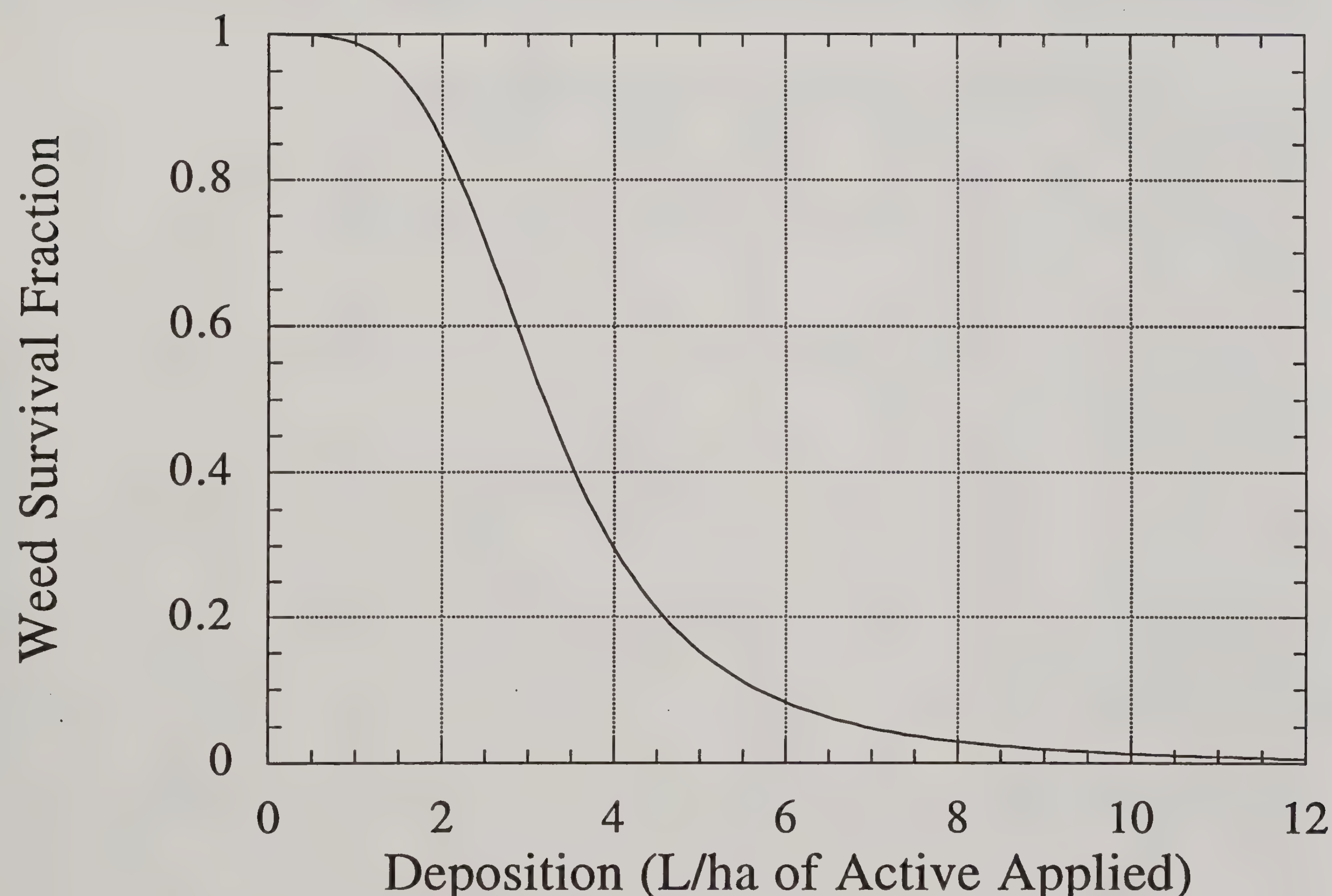

Figure 3. A dose-response curve illustrating eqn 3 with the parameters $a = 2.2$, $b = -1.9$, $C = 0$ and $D = 1$.

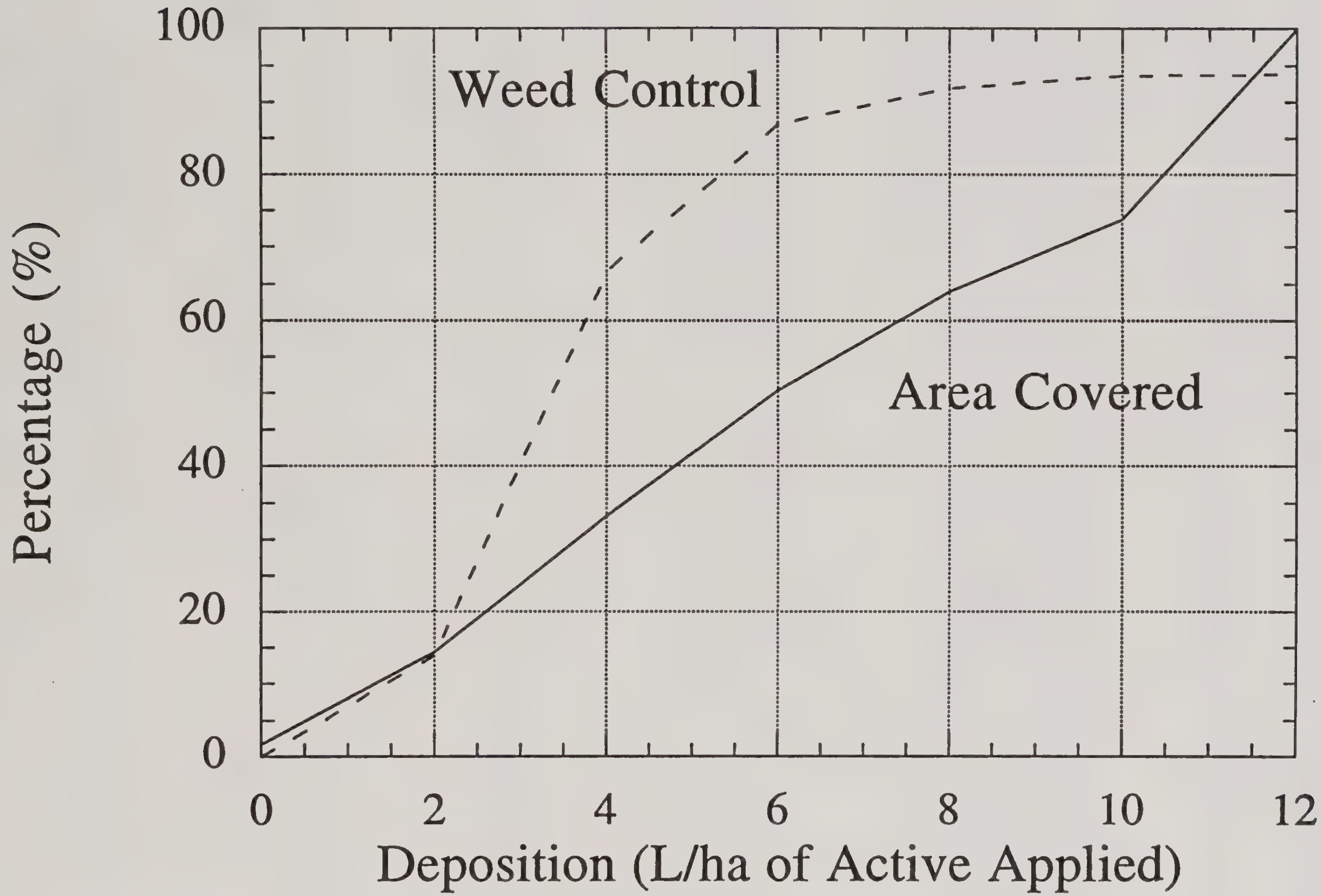

Figure 4. A plot of the consequences of the deposit frequency distribution (shown in Figure 2) with the dose-response curve (shown in Figure 3). The overall percent weed control is 75.6 percent.

4. Implementation and Example

As this was the first generation of the program, and with a limited time period available (four weeks in New Zealand) for the author, we decided to keep things simple and straightforward. Thus, any complicated features (as envisioned in the final completed decision support system) were not programmed into SpraySafe Manager in this, its initial phase of development.

The SpraySafe Manager model input screen is shown in Figure 5, with details as follows:

Model Name

SpraySafe Manager is constructed around databases; therefore, every set of inputs must be identified uniquely, and saved for the user to recover at a later date (this approach avoids the need for separate input files as used in FSCBG). Calculations are sufficiently rapid (in the anticipated 486 and Pentium environments) that model predictions are never saved. The pull-down arrow to the right of the identifier (as shown in Figure 5 to the right of the box containing the information "FRI Test 2") enables the user to make a selection from previously-saved input sets.

Aircraft

A library of aircraft (along with their detailed model inputs) is maintained within SpraySafe Manager. The user selects an aircraft type only, not the details of the aircraft. Default values were obtained principally from the FSCBG aircraft library, implemented from Hardy (1987), and are displayed in Table 1. Boom height (in m), spraying speed (kph) and application rate (L/ha for the tank mix) are also entered in the Aircraft section of the model input screen.

Meteorology

Temperature (in deg C), relative humidity (percent), wind speed (kph) and wind direction (deg from along the spray block boundary, which is positioned South to North) are entered in this section of the model input screen.

Block Geometry

Here the required distances across swath are entered: the spray block width (in m), distance to the sensitive (non-target) area (m) and sensitive (non-target) area width (m). Figure 1 previously illustrated these three lengths. Bout width (m) completes the input here, and is used to determine the number of flight lines needed to spray the spray block (spray block width divided by bout width).

Nozzle / Drop Size

A library of nozzles and the spray materials tested with these nozzles is also included in SpraySafe Manager. Nozzle angle (in deg where 0 deg is straight back) and wind tunnel speed (m/s) are shown for reference only. The user selects one of the nozzle types and spray materials, and the drop size distribution is recovered for use in FSCBG/NZ. Currently, the spray material is by code only, with the available choices as shown in Table 2. A default application rate of 100 L/ha was used to generate the database

values here, although the actual application rate entered by the user will adjust the amount of active and additives present in the simulation. There are 27 entries in the database (from B. Richardson, 1995, private communication). The number of nozzles is also entered in the Nozzle/DropSize section of the model input screen as well.

All input variables are limited by minimum and maximum values, with these limits given in Table 3. FSCBG/NZ will not run if any model input variable is outside its specified limits.

Computations are performed by clicking on the "Continue" button near the bottom of the screen. Success (charting a moving bar approximating time to completion of the calculation) results in the Initial Deposition (Single Flight Line) plot as shown in Figure 6. Zero on the horizontal scale is the downwind spray block boundary. The various options of Environment, Efficacy and Productivity may in turn be accessed by the user (clicking on the "tab" identifiers near the top of the screen), using as a basis the Initial Deposition from FSCBG/NZ and other calculated (and saved) variables.

Environmental

This screen is shown in Figure 7, presenting the results of overlapping the deposition in the spray block for the necessary number of flight lines. On the Environmental screen the percentages of deposited active spray material are summarized for the spray block, the downwind area to the sensitive (non-target) area, the sensitive (non-target) area, and the spray material still airborne beyond the defined sensitive (non-target) area. If possible, the buffer distance (in m) to a NOEL deposition level of 0.01187 L/ha (typical of Roundup on rye grass) is also calculated. Buffer distance can be no larger than the spray block width entered on the model input screen, or a warning message will be displayed. Figure 8 presents the Overlap Deposition (Multiple Flight Lines) plot. Other stored plots may be recovered by selecting them in the right-hand column under "Graphs".

Efficacy

This screen is shown in Figure 9 for the default case and shows several deposition levels (in L/ha and including the target level of the simulation), the percent area covered by each incremental band of deposition (from the deposition value shown to the one above it -- the top deposition is for all values higher than it), and the percent weed control for that incremental band of deposition. The middle column is developed by solving eqn 2, while the right hand column is developed by solving eqn 3. The overall weed control percentage (a weighted average of percent area covered times percent weed control) is given below the tabular data.

Productivity

This screen is shown in Figure 10 for the default case. Additional data entries for productivity (all of which will be internally corrected if they are outside the minimum and maximum values summarized in Table 3) include:

Tank Capacity (in L)
Spray Block Length (m and therefore defining the rectangular spray block)
Ferry Distance (m from the helipad or airport to the spray block)
Ferry Speed (kph)
Turning Time (sec for the aircraft to reverse direction at the end of a flight line)
Loading Time (min on the ground to refill the tank)
Cost ($/hr for the aircraft)

Productivity computations recover the estimated cost of the project (in $/ha) and work rate (ha/hr). An additional section on the lower part of the screen may be used to examine the optimal productivity by changing the coefficient of variation (CV in percent) of the multiple flight line deposition pattern across the spray block, and seeing its effect on bout width (m), cost and work rate.

Sensitivity

Found at the bottom of the Environmental, Efficacy and Productivity screens, Sensitivity enable the user to select an input variable and a range across which to vary the value of that variable; then, by clicking the "Calculate" button, FSCBG/NZ performs a series of calculations to generate the desired result. The variables that may be accessed as Sensitivity Variables include:

Wind Speed (kph)
Wind Direction (deg from flight direction)
Temperature (deg C)
Relative Humidity (percent)
Boom Height (m)
Bout Width (m)
Application Rate (L/ha)

For example, suppose that the effect of boom height on buffer distance and efficacy is desired, across the range from 5 m to 25 m. After entering the data and waiting for the computation (the inputted data will be corrected if it is beyond the minimum and maximum values given in Table 3), the resulting plots of buffer distance (Figure 11), overall weed control (Figure 12), mean deposition within the spray block (Figure 13), and coefficient of variation within the spray block (Figure 14) are obtained. Here it may be seen that as the boom height increases (as the aircraft flies higher above the ground), the buffer distance increases (until it is in fact beyond the limits imposed by the input), overall weed control reaches a limiting value (for the model inputs specified -- the inputs may now be changed and SpraySafe Manager rerun to improve the overall weed control level if so desired), the mean deposition also levels off (as the aircraft flies higher, the deposition becomes more uniform on the ground), and the coefficient of variation reaches toward zero (consistent with the uniform deposition pattern).

Clearly, the ease with which these computations can be performed, and their presentation to the user for interpretation, make SpraySafe Manager a powerful computational asset even in its preliminary development stage.

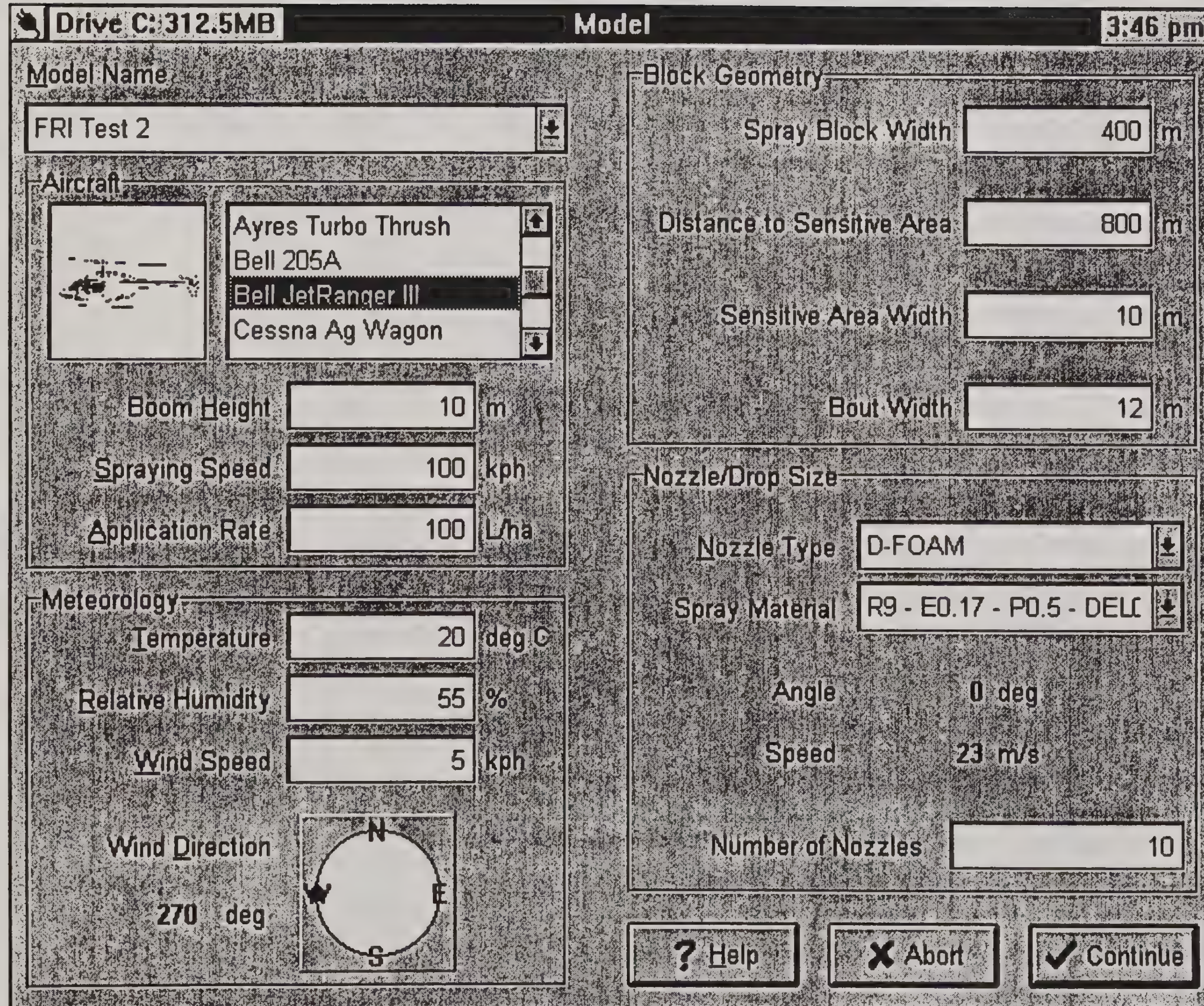

Figure 5. The SpraySafe Manager model input screen.

Table 1. Aircraft Types in SpraySafe Manager.

Name	Type
Air Tractor AT-301	fixed-wing
Ayres Turbo Thrush	fixed-wing
Bell 205A	helicopter
Bell Jet Ranger III	helicopter
Cessna Ag Wagon	fixed-wing
Fletcher	fixed-wing
Hiller Soloy Turbo	helicopter
Hughes 300C	helicopter
Hughes Cayuse 500C	helicopter
Schweizer Ag Cat	fixed-wing
Squirrel	helicopter

Table 2. Nozzle Types and Spray Materials in SpraySafe Manager.

Nozzle Types: D6, D8/46 and Delevan Foaming

Tank Mix Proportions of Nonwater Components
(generating a 100 L/ha application rate)

Delafoam (% volume)	Escort (kg/ha)	Pulse (% volume)	Roundup (L/ha)	Trounce (kg/ha)
		0.25	9.0	
0.12		0.25	9.0	
0.4		0.25	9.0	
		1.0	9.0	
0.4		1.0	9.0	
	0.17	0.5	9.0	
0.4	0.17	0.5	9.0	
0.12	0.17	0.5	9.0	
	0.17	0.5		
0.4	0.17	0.5		
		1.0		4.0
0.4		1.0		4.0
		0.5		4.0
	0.17	0.5		4.0
0.4	0.17	0.5		4.0
0.4		0.5		4.0
		0.25		4.0
0.4		0.25		4.0

Table 3. SpraySafe Manager Input Variable Limits.

Model Limits

Variable Name	Minimum Value	Maximum Value
Boom Height (m)	1	30
Spraying Speed (kph)	20	300
Application Rate (L/ha)	5	800
Temperature (deg C)	-10	40
Relative Humidity (percent)	5	100
Wind Speed (kph)	1	30
Spray Block Width (m)	10	2000
Distance to Sensitive Area (m)	0	1000
Sensitive Area Width (m)	2	1000
Bout Width (m)	2	50
Number of Nozzles	2	80

Productivity Limits

Variable Name	Minimum Value	Maximum Value
Tank Capacity (L)	10	1000
Spray Block Length (m)	10	2000
Ferry Distance (m)	0	50000
Ferry Speed (kph)	20	300
Turning Time (sec)	5	120
Loading Time (min)	1	30
Cost ($/hr)	100	1500

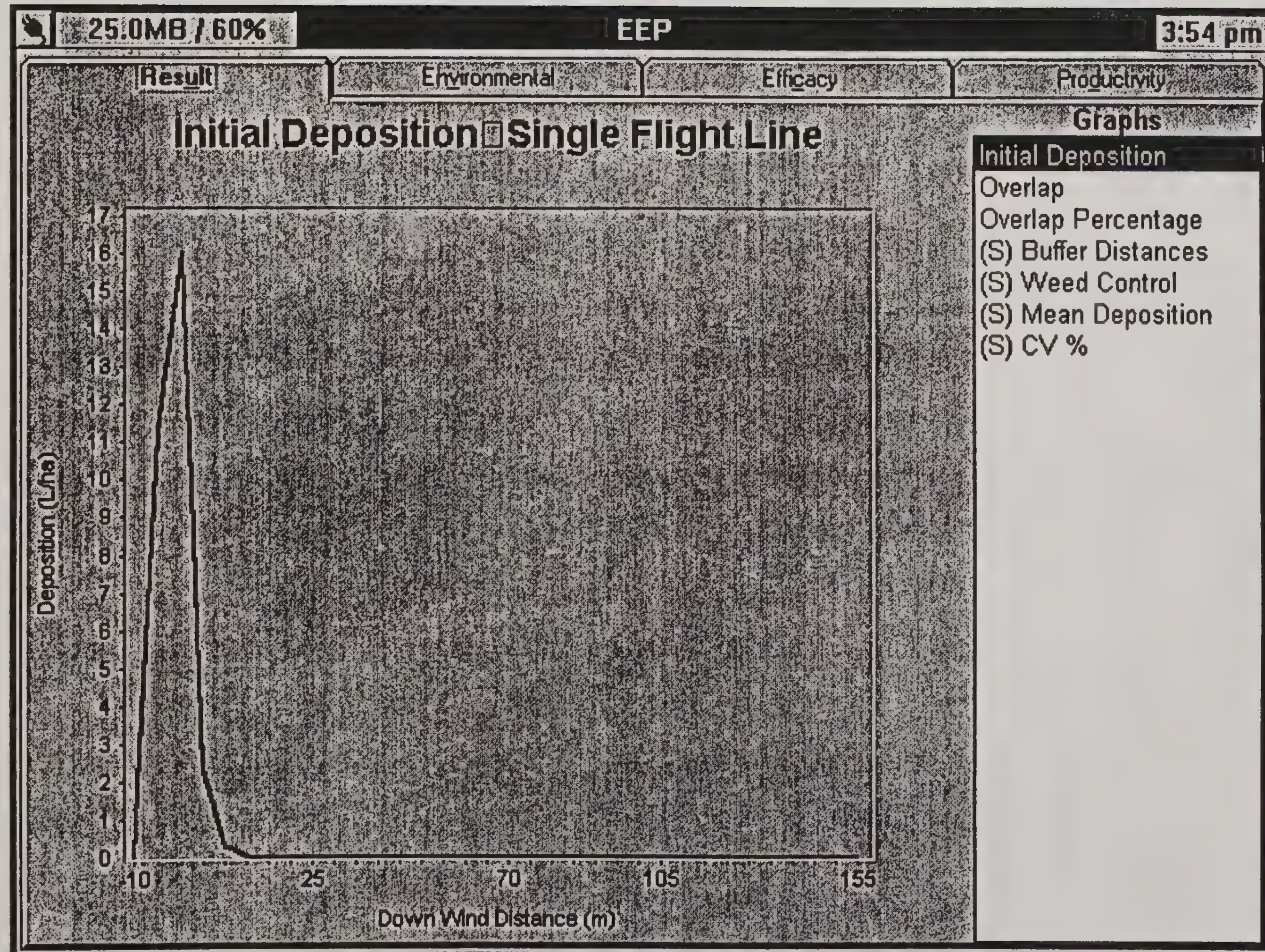

Figure 6. The initial deposition for a single flight line from SpraySafe Manager for its default conditions.

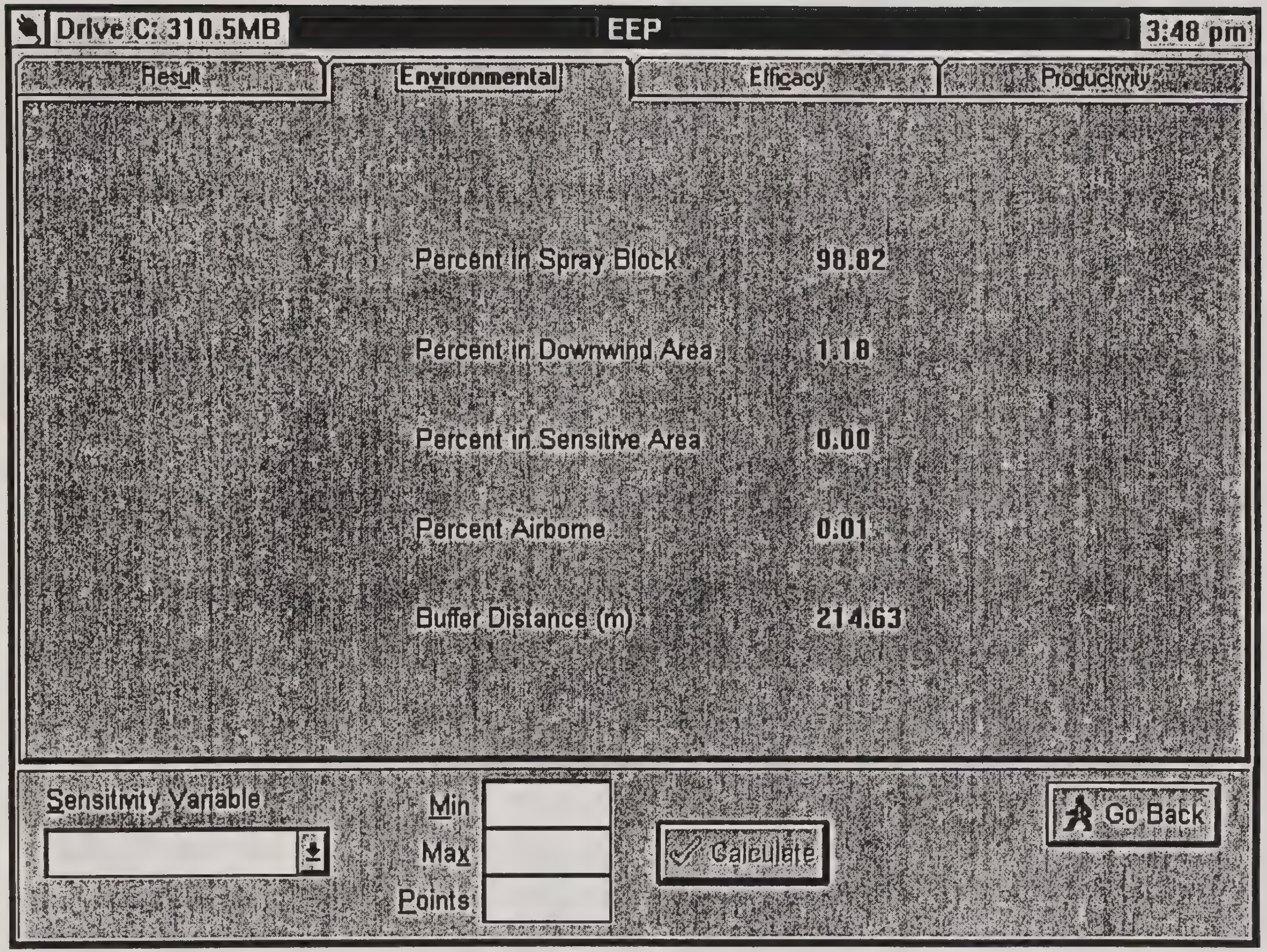

Figure 7. The SpraySafe Manager environmental module screen.

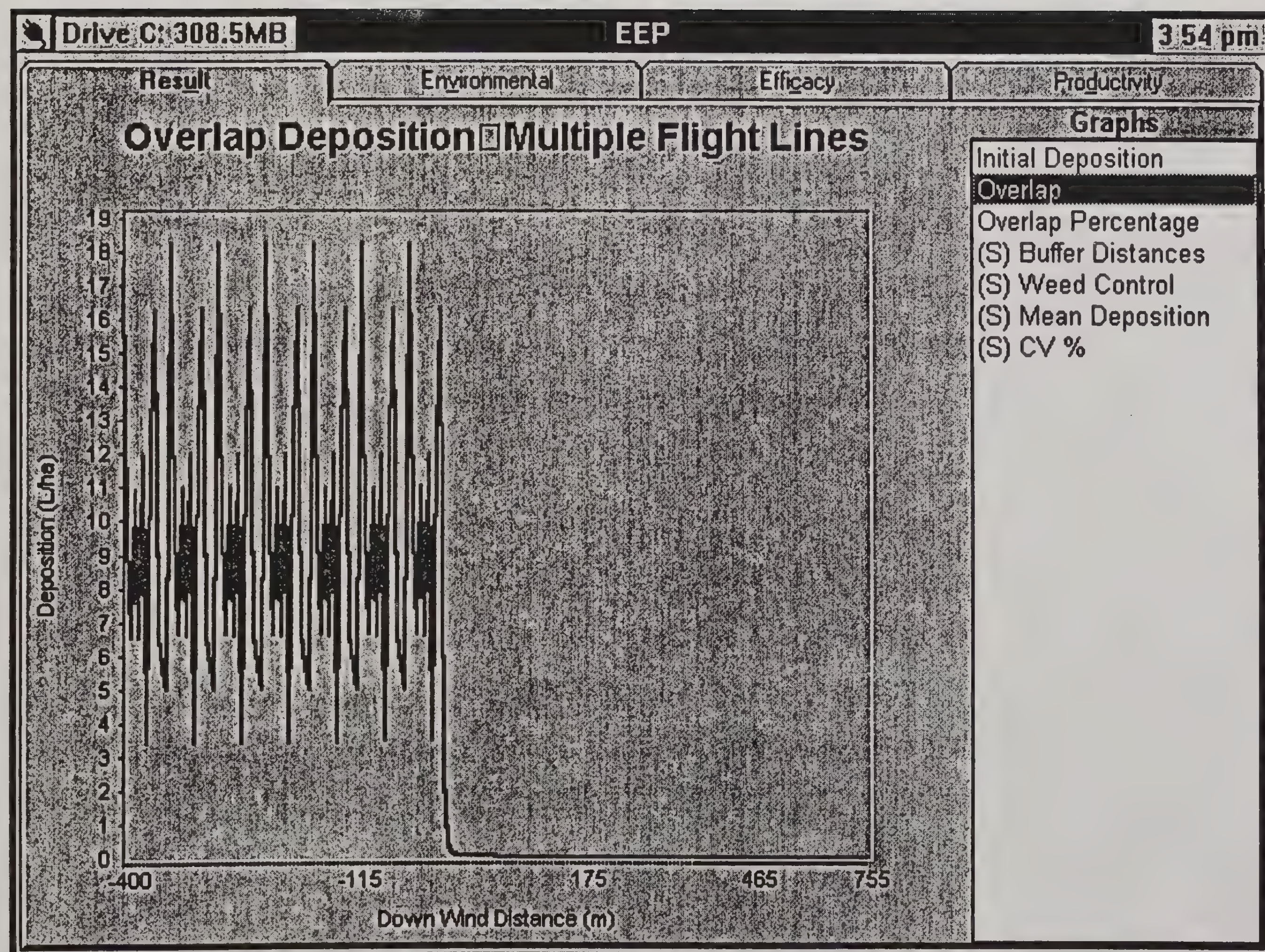

Figure 8. The overlap deposition for multiple flight lines from SpraySafe Manager for its default conditions.

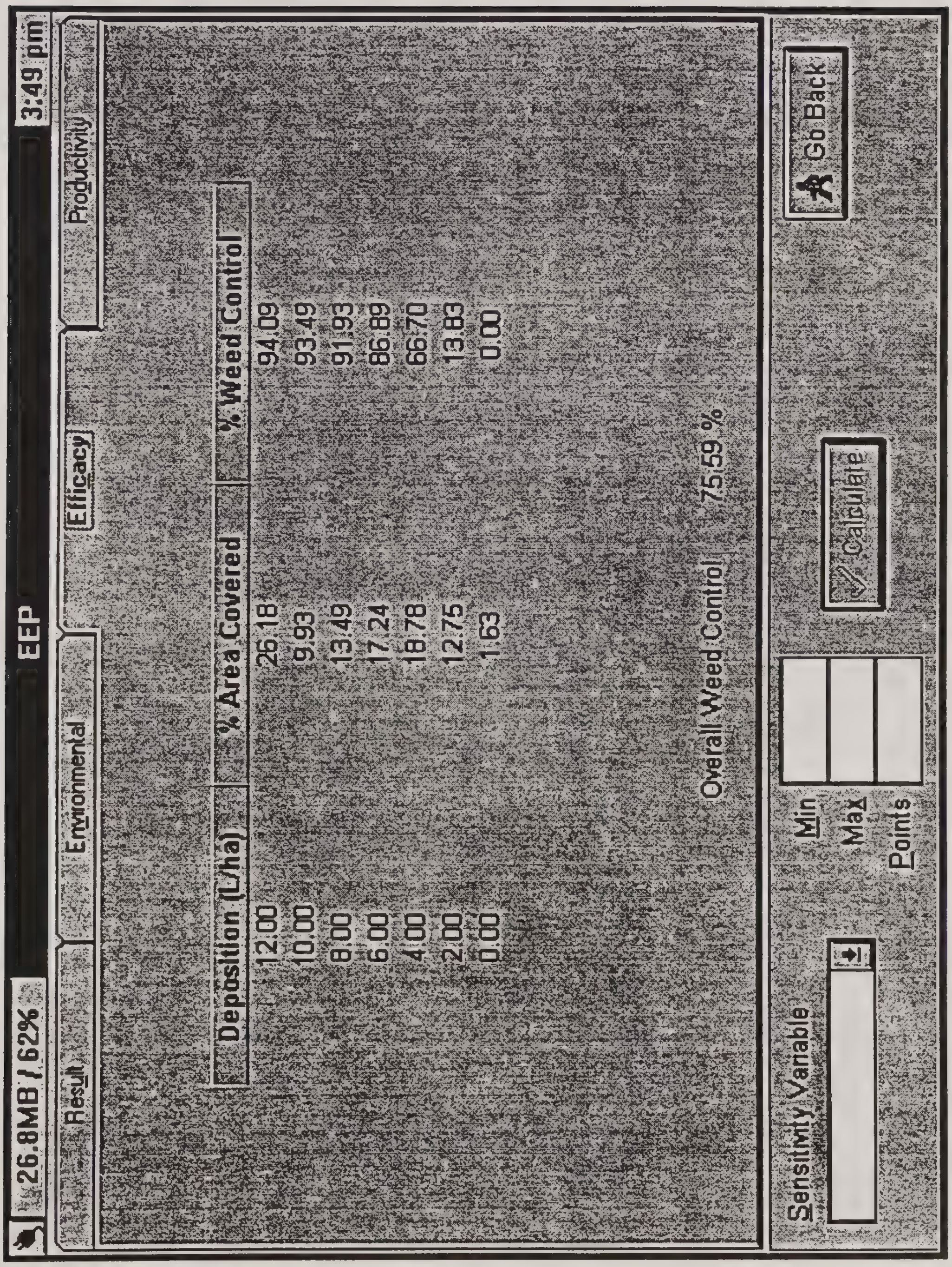

Figure 9. The SpraySafe Manager efficacy module screen.

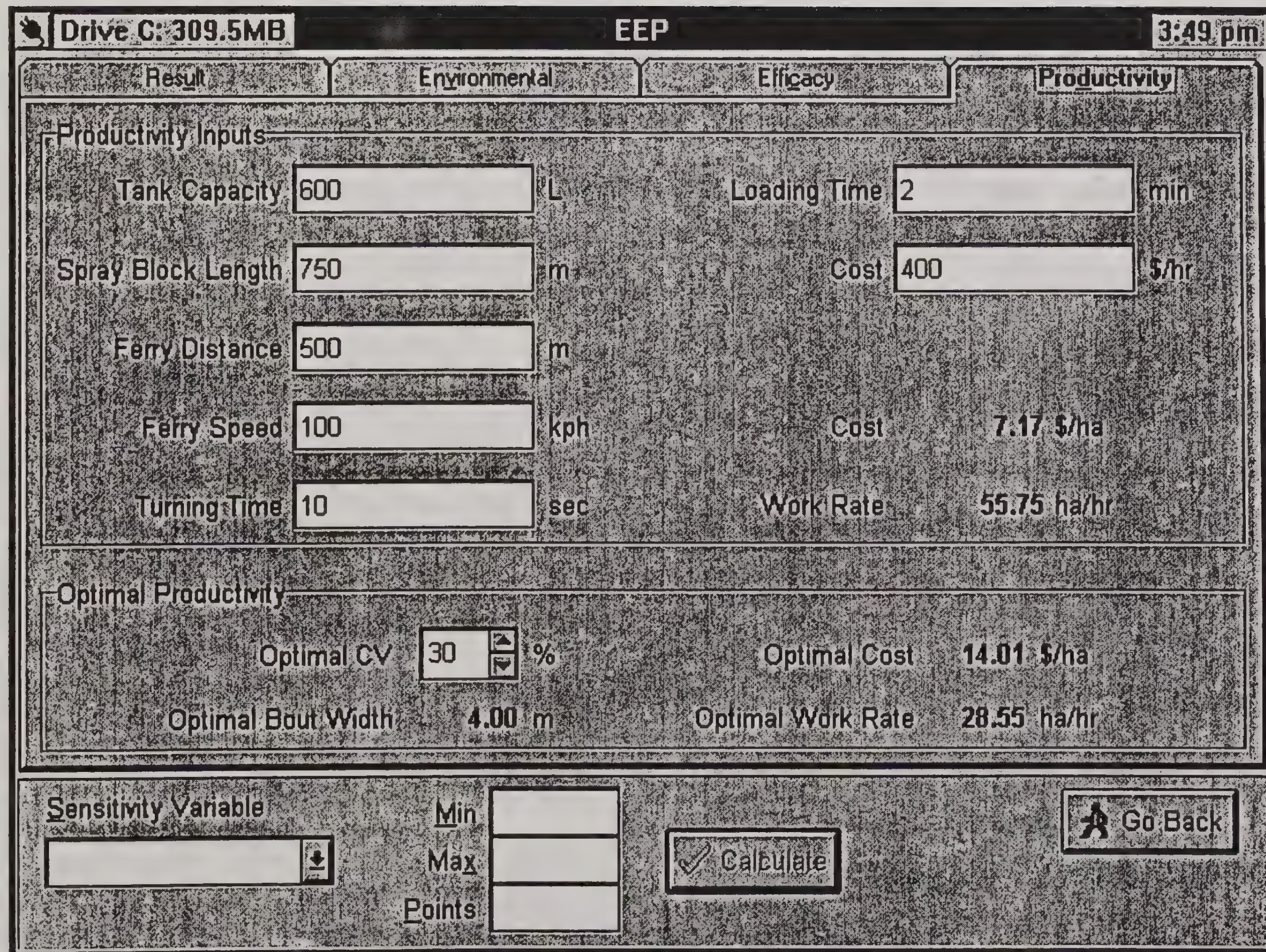

Figure 10. The SpraySafe Manager productivity module screen.

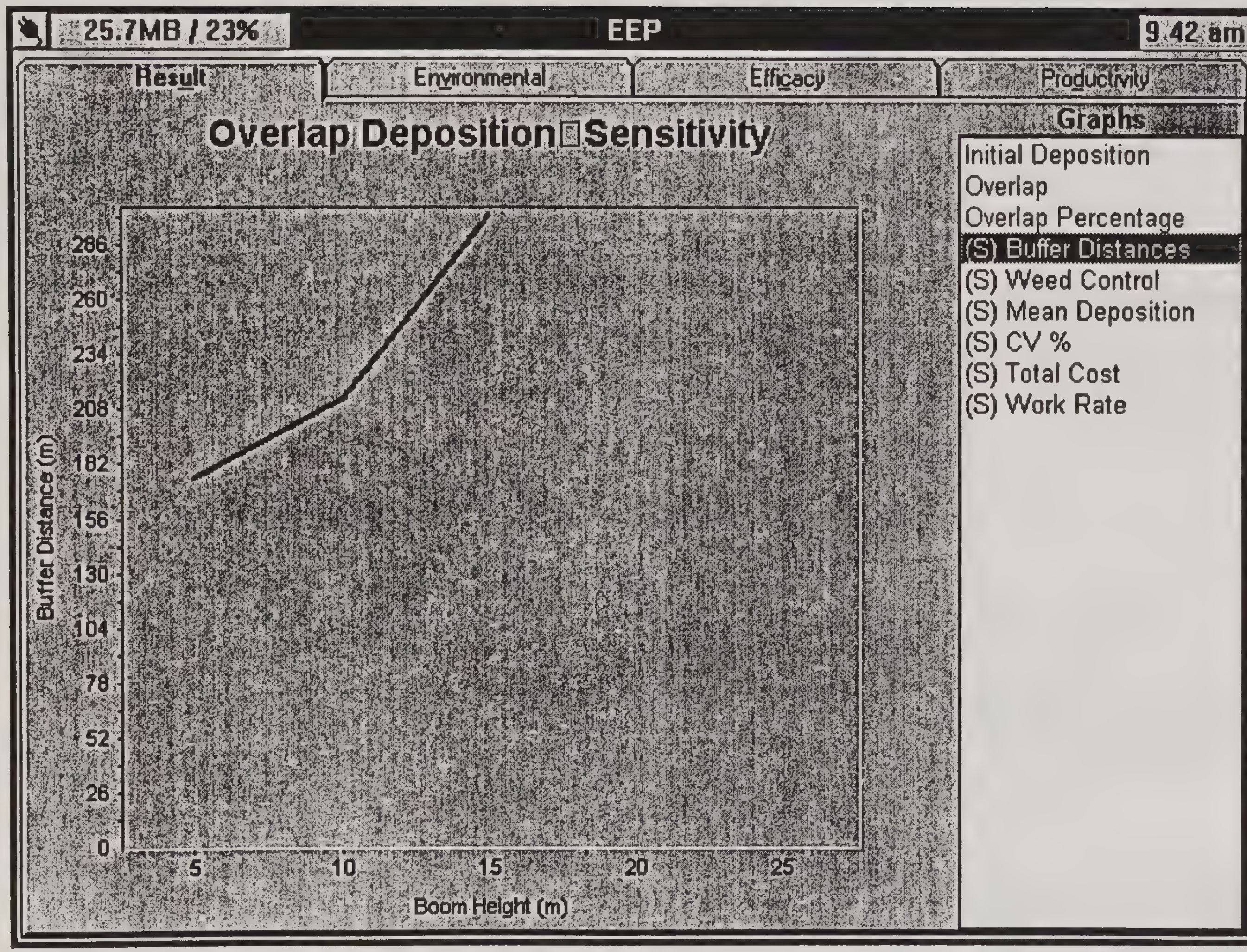

Figure 11. The sensitivity of buffer distance to boom height for the default conditions.

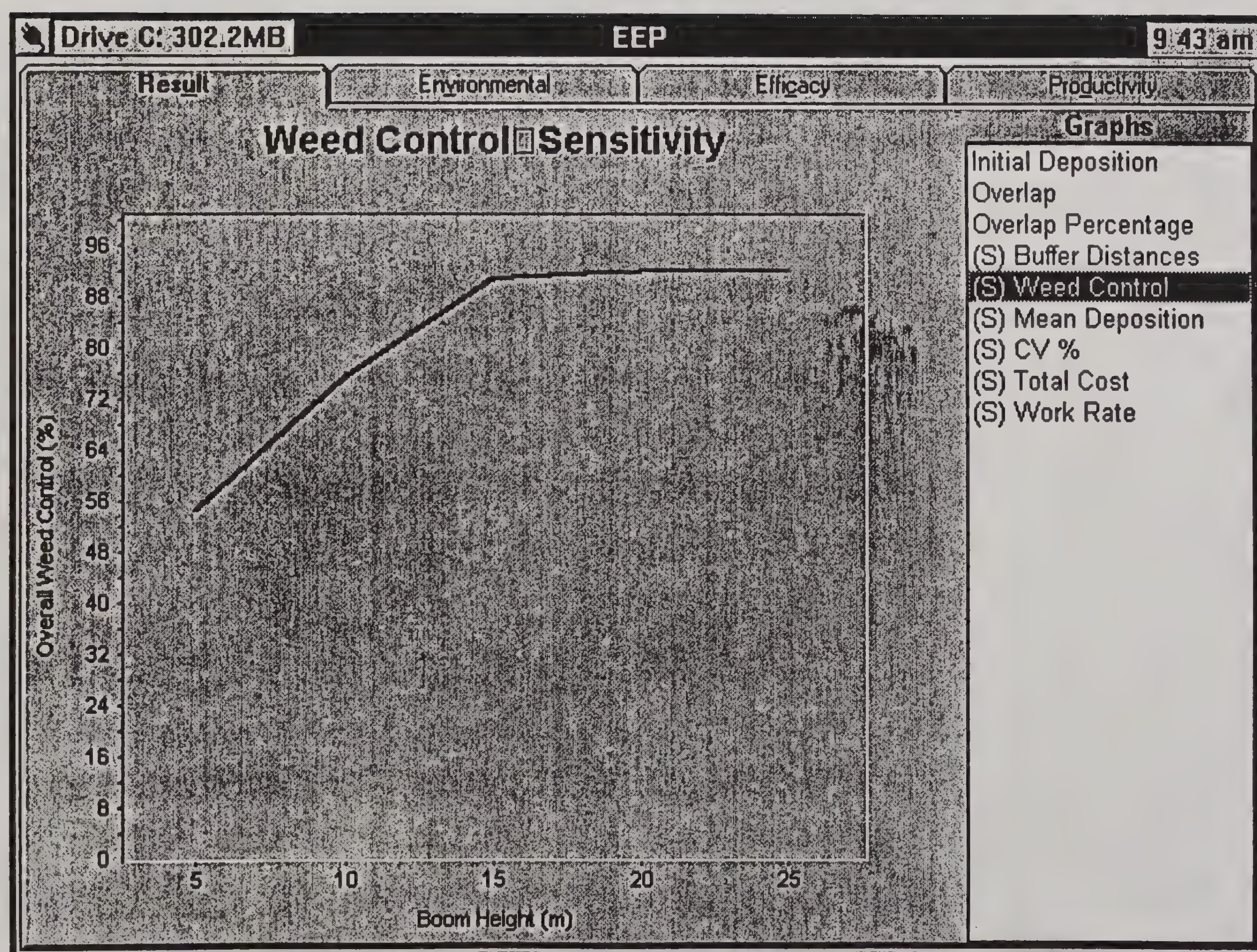

Figure 12. The sensitivity of overall weed control to boom height for the default conditions.

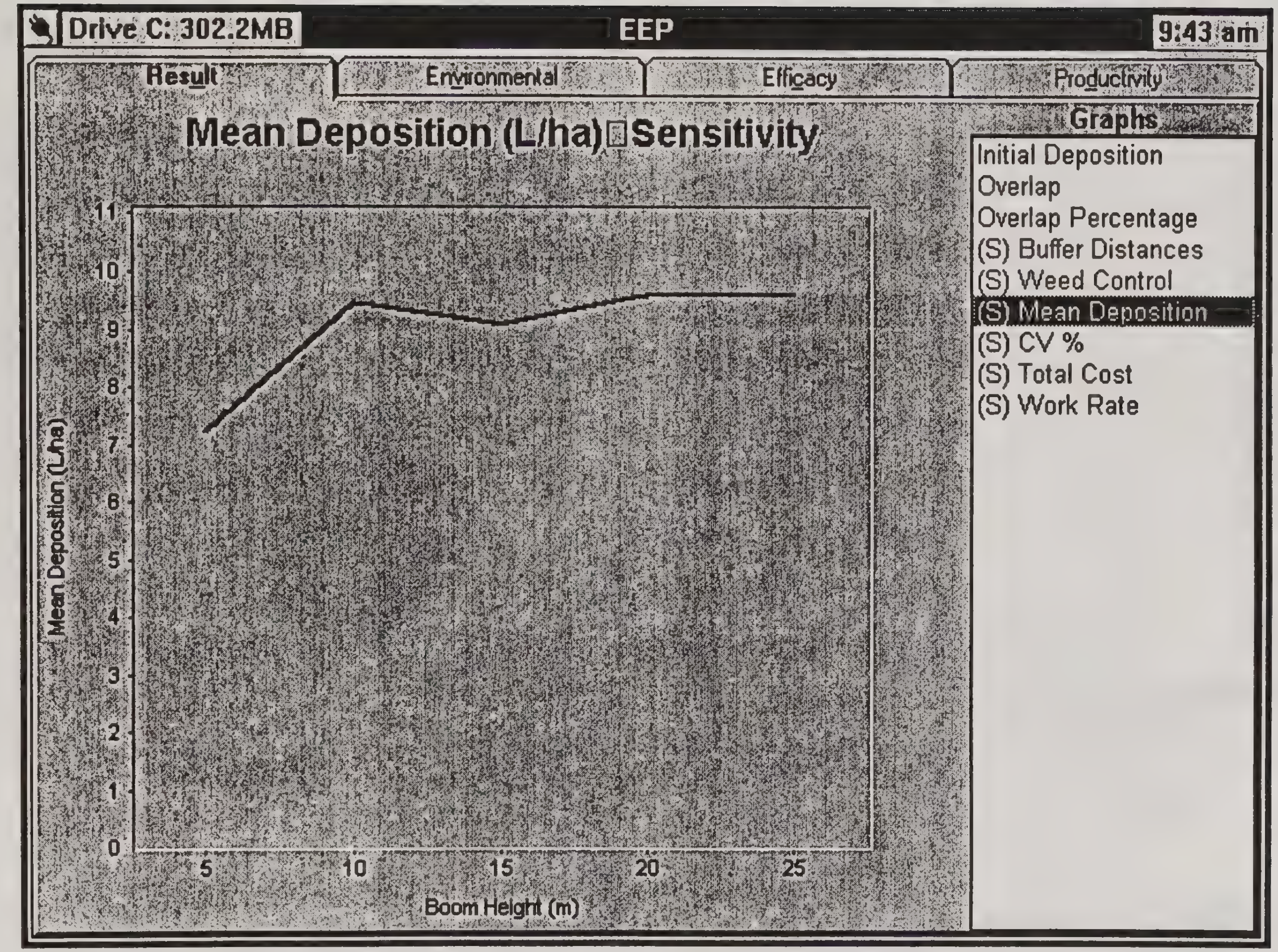

Figure 13. The sensitivity of mean deposition to boom height for the default conditions.

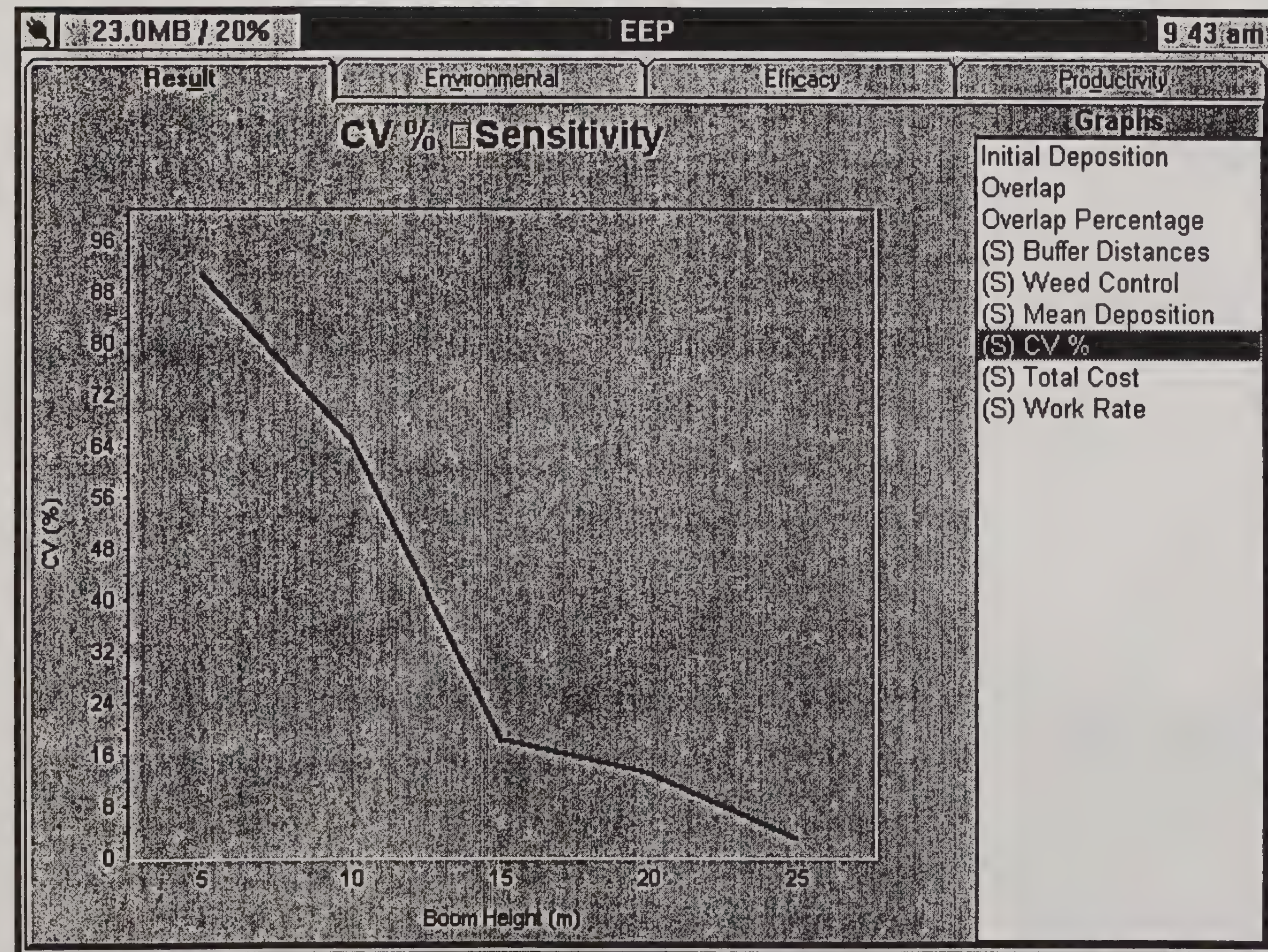

Figure 14. The sensitivity of coefficient of variation to boom height for the default conditions.

5. Future Development

In four weeks of development at New Zealand Forest Research Institute, we were able to develop only some of the features in SpraySafe Manager needed to achieve all of our eventual program goals. Future needs include the following:

Extensive Databases

Both aircraft and nozzle (drop size distribution) libraries must be expanded to include all current spray aircraft, and a strong representation of the nozzles and spray materials and tank mixes sprayed in New Zealand. In addition, we expect to add a dose-response library to complement the spray material with the actual effect of the spray material on plant species of interest (with this step we would eliminate the fixed NOEL placed in the program). Also, an extensive sensitivity analysis database will be added, including the effects of changes in model inputs on deposition patterns. This sensitivity analysis (Teske 1995) is an extension of Teske and Barry (1993) and includes a more detailed examination of specific input variables, and an emphasis on bout width and buffer distance.

Generalized Block Geometry

We expect to incorporate a procedure whereby the user can enter an irregularly shaped spray block and sensitive (non-target) area, rather than the simple geometry included at present.

File Operations and Program Portability

Few of the tools needed to implement the present version of SpraySafe Manager onto machines other than the development machine are in place, including the ability to save new input values in the database, print inputs (and results) to files for exporting to other graphics environments, and setting menu screen size and appearance.

Context-Sensitive Help

We expect to include an extensive Help facility, to provide guidance to the user regarding any input to the model, or the interpretation of any generated output.

Additional Modules

We expect to add four additional modules to SpraySafe Manager, including a Calibration Module (to provide simple calibration procedures to select appropriate nozzle type, number and bout width, and overlap analyses of swath patterns), Training (providing basic information on aerial application and access to the sensitivity analysis database to discover trends in input variable changes) and Aerial Applicator Advisor (a rule-based decision support mechanism for suggesting ways of improving the solution presented to the user by the model). Additionally, we will include the option for the advanced user to access all databases. Cost-benefit analysis, and all other topics discussed previously in this paper, will also be added.

6. Conclusions

The partnership work undertaken in New Zealand has made significant progress toward the development of a decision support system for use by timber managers who apply pesticides. Much work remains before SpraySafe Manager will meet the goals of both New Zealand and United States forest and agricultural managers who plan, conduct and evaluate the benefits and impact (positive and negative) of aerial application of pesticides. The modules developed in New Zealand will be implemented into the USDA Forest Service model FSCBG, and will be used as a starting point from which to build an extensive and detailed SpraySafe Manager. This work demonstrates what can be achieved with close cooperation and resource sharing between governmental agencies (in this case the United States and New Zealand) when common interests are addressed.

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